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Relative Preliminary Radiation Doses from the Transport of Nuclear Waste to Potential Gulf Interior Repository Sites

Technical Report

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December, 1980

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50 Beale Street
P. O. Box 3965
San Francisco, CA 94119

ONWI
Office of Nuclear Waste Isolation

BATTELLE Project Management Division

MV

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II

ABSTRACT

Total radiation doses resulting from the transport of spent fuel from 54 nuclear reactors to 7 potential waste repository sites in the southern United States were determined and compared. Calculations included doses to the surrounding population, transport crews, and persons in other vehicles and at rest stops. Calculations were based on a maximum allowable dose rate of 2 mrem per hour for truck crews, and on results from integrated dose equations for other elements of the population. Values for each population group were summed to give total doses; the total doses ranged from 46 to 75 person-rem per year, of which about 75 percent would be received by the two-person truck crews. These total dose values would amount to roughly 0.005 percent of background ratiation, on an average person-rem per year basis. Two conclusions were drawn: (1) only small differences in transportation-related doses exist among the seven repository sites and (2) the transportation-related dose to the general population is so low that transportation (under routine, non-accident conditions) is not a principal criterion for repository site selection.

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1.0 INTRODUCTION

This report is published in support of the National Waste Terminal Storage (NWTS) program. The objective of the NWTS program is development of terminal waste storage facilities in deep, stable geologic formations for nuclear wastes generated from commercial nuclear facilities and transuranic nuclear waste for which the federal government is responsible. The Office of Nuclear Waste Isolation (ONWI) is administering one portion of the NWTS program. This report is designed to assist the Site Evaluation Committee of ONWI in recommending salt domes in the Gulf Interior Region (GIR) for further study.

The purpose of this report is to compare and rank seven candidate salt domes based on relative radiation doses to the population resulting from transport of nuclear waste to each of the seven domes. This report is intended as one in a series of transportation studies to assist in repository site selection, and to predict waste transportation impacts.

2.0 SUMMARY AND CONCLUSIONS

When these studies were conducted, seven salt domes in the Gulf Interior Region were under consideration for recommendation as a terminal storage site for high level nuclear waste. This report compares the seven salt dome locations in the Gulf Interior Region with regard to relative total doses to the population due to shipment of spent fuel assemblies under normal (non-accident) transportation conditions. Total dose is defined here as the sum of radiation doses to all persons potentially exposed in any way to the waste during transport. This includes truck and train crews, other travelers along the way, attendants at rest stops, and persons living near the transport routes. The comparison of total doses due to transport is to be used as one factor in recommending one or more domes for future analysis and ultimate selection of a repository site.

The total dose comparison was based on methods of dose calculations developed by the U.S. Nuclear Regulatory Commission (1977), computer routing models provided by Oak Ridge National Laboratory[(a)] (Logistics Systems, Inc., 1980), and a number of assumptions regarding amounts, types and age of spent fuel to be shipped, shipping casks used, transportation methods, and population density. The following results were obtained for total dose due to transportation of nuclear waste to each of the seven domes:

(a) Letters transmitted from D. S. Joy of ORNL to J. T. Chappell of Bechtel, May 15 and 22, 1980.

Dome	Total Dose	Dose to Truck Crew	Total Dose Excluding Truck Crew
	-------person-rem/year----------		
Richton, MS	46	38	8
Cypress Creek, MS	48	40	8
Lampton, MS	49	41	8
Vacherie, LA	62	51	11
Rayburn's, LA	62	51	11
Keechi, TX	74	62	12
Oakwood, TX	75	63	12

These doses represent annual total doses to the affected populations. They are based on the maximum spent fuel shipment year (2004) for 70 reactors in the Southern U.S. Shipments will be by rail for those reactors served by railroads and by truck for those reactors not served by railroads.

The conclusions of this report are twofold:

(1) Virtually no differences exist in total doses among domes within the same states, and only small differences exist in total doses among domes in different states.

(2) Because the dose levels are very low when compared with normal background radiation doses to the population, it appears that the total dose due to transportation under normal non-accident conditions is not a principal consideration for repository site selection. For instance, the highest dose received by population

exposed during transportation of spent fuel from all the reactors to a dome (Oakwood Dome in Texas) would be 75 person-rem/year while the dose received by the same population due to all other causes is estimated to be 1.5×10^6 person-rem/year. The dose received by the population from normal transportation of spent fuel from all reactors to Oakwood Dome would be about 0.005 percent of that from background radiation. Results are similar for all domes. Other facets of the transportation issue, such as comparative costs, accident risks, and public acceptability may be more significant and require further study.

3.0 STUDY BASES

The methodology used in this study is based on current facts and assumptions about national policy, urban patterns, the nuclear industry, proposed repositories, and transportation modes and routes. This conceptual model was used to determine total doses under normal (non-accident) conditions to the population along transportation routes.

3.1 BACKGROUND

The ONWI Site Evaluation Committee is evaluating seven salt domes in the Gulf Interior Region in order to recommend one or more domes that might prove suitable for further study. Each dome is being evaluated on the basis of 10 major criteria, 30 subcriteria, and more than 100 considerations. This report addresses Criterion 8: Demography; Subcriterion 8.2: Transportation of Wastes; Consideration: Shipment Risk (U.S. Department of Energy, 1981). It provides input to a preliminary comparison of the seven Gulf Interior domes on the basis of potential total doses to the general population along reactor-to-respository transportation routes.

A preliminary comparison of the domes is appropriate at this time for the following reasons:

- Transportation impacts of spent fuel have received relatively little consideration in the site evaluation process in the Gulf Interior Region. The relative importance of transportation as a siting criterion should be established.

- The Site Evaluation Committee required results of this study in mid 1980 for further evaluation of the seven domes.

This report is based on data provided by ONWI and Oak Ridge National Laboratory (ORNL) regarding spent fuel sources and shipments. ORNL's base growth case predicts a nuclear generation capacity of 175 GWe in the year 1995[a], (Office of Nuclear Waste Isolation, 1980a), which nearly coincides with the presently committed and planned nuclear generation capacity (American Nuclear Society, 1980). This logistic information has provided preliminary guidance to repository designers regarding the regional repository concept. ONWI additionally directed that the results of the ORNL transportation models be used as a basis for this report.[a]

It was assumed that four regional repositories would be developed, one each in the western, north-central, north-eastern, and southern regions (Interagency Review Group, 1979). The service area of each repository would include one or more National Electric Reliability Council (NERC) power generation regions; the southern repository

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(a) Letter transmitted from M. W. Anthony of ONWI to L. B. Shappert of ORNL, April 30, 1980.

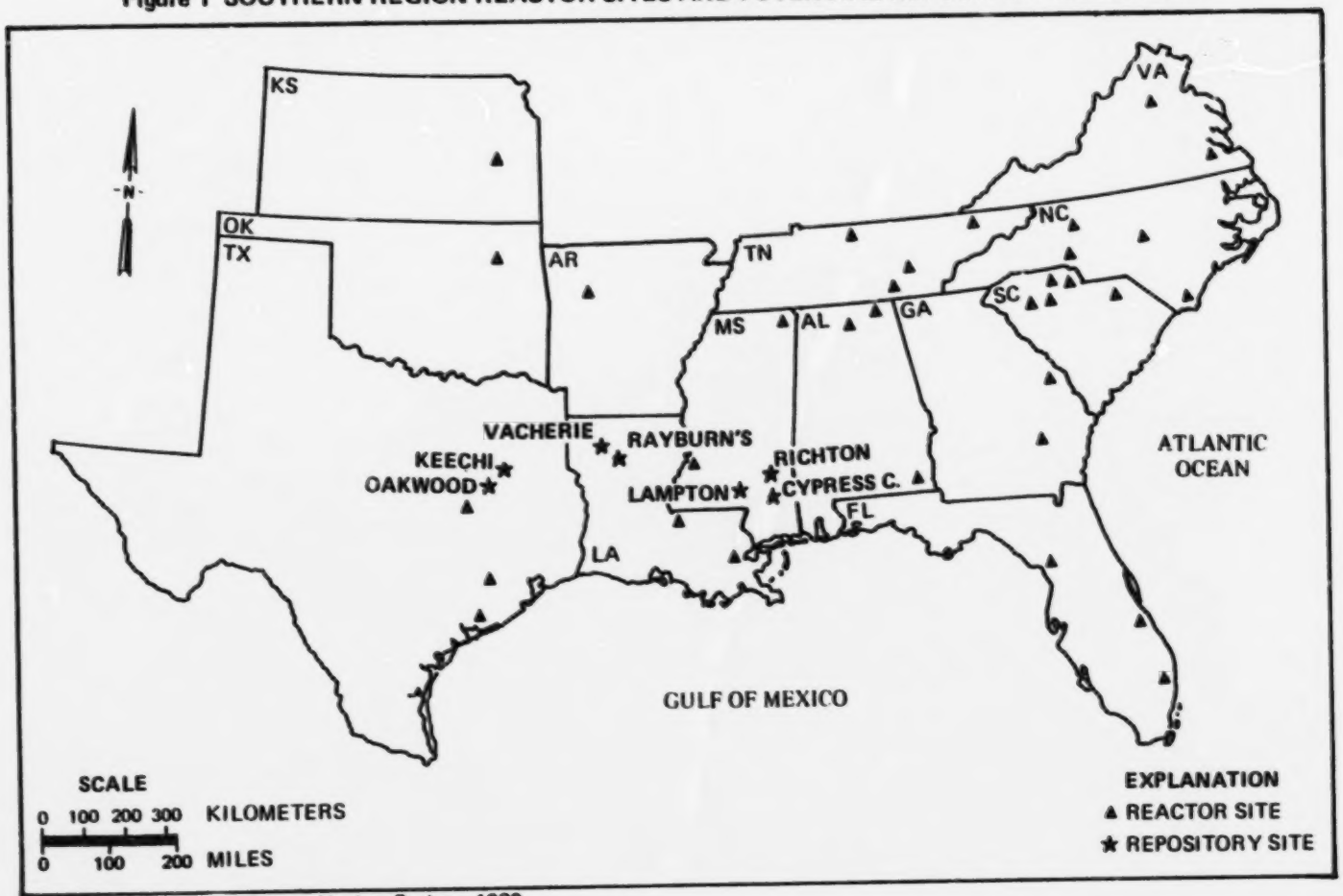
would serve NERC regions 2, 7, and 8[a] (Office of Nuclear Waste Isolation, 1980a).

The operable, under construction and on order nuclear reactors in NERC regions 2, 7, and 8, the southern study region, are shown in Table 1 and Figure 1. There are 70 nuclear reactors located at 33 sites in the southern study region; 20 are boiling water reactors and 50 are pressurized water reactors. These reactors are situated in 13 southern states: Texas, Oklahoma, Kansas, Louisiana, Arkansas, Tennessee, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina and Virgina. Table 2 lists the waste shipment characteristics at peak year for the 70 reactors.

The seven salt domes under study as potential repository sites in the southern region are: Rayburn's and Vacherie in Louisiana; Cypress Creek, Lampton and Richton in Mississippi; and Keechi and Oakwood in Texas. These salt domes and their locations are shown in Figure 1 and described in Table 3.

(a) Letter transmitted from M. W. Anthony of ONWI to L. B. Shappert of ORNL, April 30, 1980.

Figure 1 SOUTHERN REGION REACTOR SITES AND POTENTIAL REPOSITORY LOCATIONS



Source for Reactors: American Nuclear Society, 1980

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Table 1

NUCLEAR POWER PLANTS OPERABLE, UNDER CONSTRUCTION, OR ON ORDER
AS OF DECEMBER 31, 1979

Status Code	Plant name	Location	State	MWe Capacity
		Region 2		
b	Southwest Texas Project Nos. 1 and 2	Palacios	TX	1250 each
b	Comanche Peak - 1	Glen Rose	TX	1150
b	Comanche Peak - 2	Glen Rose	TX	1100
c	Allens Creek - 1	Wallis	TX	1160
		Region 7		
a	Turkey Point - 3 and 4	Florida City	FL	652 each
a	St. Lucie - 1	Fort Pierce (12 mi SE)	FL	810
b	St. Lucie - 2	Fort Pierce (12 mi SE)	FL	810
a	Surry - 1	Williamsburg (8 mi S)	VA	784
a	Surry - 2	Williamsburg (8 mi S)	VA	782
a	Oconee - 1 and 2	Seneca	SC	886 each
a	Oconee - 3	Seneca	SC	871
a	Browns Ferry - 1, 2 and 3	Decatur (10 mi NW)	AL	1067 each
b	Hartsville - 1, 2, 3 and 4	Hartsville (5 mi SE)	TN	1233 each
b	Bellefonte - 1 and 2	Scotsboro (7 mi ENE)	AL	1213 each
b	Yellow Creek - 1	Cornith (15 mi E)	MS	1287
b	Yellow Creek - 2	Cornith (15 mi E)	MS	1285
b	Sequoyah - 1 and 2	Soddy-Daisy	TN	1148 each

Table 1 (Cont'd)

Status Code	Plant name	Location	State	MWe Capacity
		Region 7 (Continued)		
b	Watts Bar - 1 and 2	Spring City	TN	1177 each
a	Joseph M. Farley - 1	Dothan (16 mi E)	AL	829
a	Joseph M. Farley - 2	Dothan (16 mi E)	AL	829
a	Crystal River - 3	Red Level	FL	825
b	Vogtle - 1 and 2	Waynesboro	GA	1121 each
b	Shearon Harris - 1, 2, 3 and 4	Newhill	NC	915 each
b	McGurie - 1 and 2	Terrell	NC	1180 each
b	Catawaba - 1 and 2	Clover	SC	1180 each
c	Perkins - 1, 2 and 3	Mocksville	NC	1287 each
b	Cherokee - 1 and 2	Gaffney	SC	1287 each
c	Cherokee - 3	Gaffney	SC	1287
a	Robinson - 2	Hartsville (6 mi NW)	SC	740
a	North Anna - 1	Mineral	VA	908
b	North Anna - 2, 3 and 4	Mineral	VA	907 each
b	Virgil C. Summer - 1	Columbia (26 mi NW)	SC	900
a	Edwin I. Hatch - 1	Baxley (11 mi N)	GA	786
a	Edwin I. Hatch - 2	Baxley (11 mi N)	GA	795
a	Brunswick - 1 and 2	Southport	NC	821 each
b	Phipps Bend - 1 and 2	Surgoinsville	TN	1233 each
		Region 8		
b	Waterford - 3	Taft	LA	1104

Table 1 (Cont'd)

Status Code	Plant name	Location	State	MWe Capacity
		Region 8 (Continued)		
a	Nuclear One - 1	Russelville	AR	850
b	Nuclear One - 2	Russelville	AR	912
b	Wolf Creek	Burlington (4 mi NE)	KS	1150
c	Black Fox - 1 and 2	Inda (3 mi SW)	OK	1150 each
b	River Bend - 1 and 2	St. Francisville	LA	940 each
b	Grand Gulf - 1 and 2	Port Gibson	MS	1254 each

Notes: There are 70 reactors at 33 sites. Regions 2, 7 and 8 are the National Electric Reliability Council power generating regions to be served by the southern regional repository.

Status Codes: a - Units in commercial operation

b - Units under construction

c - On order, construction not started

Source: American Nuclear Society, 1980.

Table 2

SHIPMENT CHARACTERISTICS AT PEAK YEAR

REACTOR	Reactor type, Supplier and Capacity[a](MWe)	No. of Assemblies Shipped per Year	Mode of Shipment	Total shipments per plt. site per Year.
So. Texas Project No. 1	P (W-1250)	65	Rail	11
So. Texas Project No. 2	P (W-1250)	65	Rail	
Comanche Peak - 1	P (W-1150)	65	Rail	11
Comanche Peak - 2	P (W-1100)	65	Rail	
Allen Creek - 1	B (1160)	191	Rail	7
Turkey Point - 3	P (W-652)	52	Truck	52
Turkey Point - 4	P (W-652)	52	Truck	
St. Lucie - 1	P (CE-810)	52	Truck	52
St. Lucie - 2	P (CE-810)	52	Truck	
Surry - 1	P (W-784)	52	Truck	52
Surry - 2	P (W-782)	52	Truck	
Oconee - 1	P (B&W-886)	59	Truck	89
Oconee - 2	P (B&W-886)	59	Truck	
Oconee - 3	P (B&W-871)	59	Truck	
Browns Ferry - 1	B (1067)	191	Truck	143
Browns Ferry - 2	B (1067)	191	Truck	
Browns Ferry - 3	B (1067)	191	Truck	
Hartsville - 1	B (1233)	200	Truck	200
Hartsville - 2	B (1233)	200	Truck	
Hartsville - 3	B (1233)	200	Truck	
Hartsville - 4	B (1233)	200	Truck	
Bellefonte - 1	P (B&W-1213)	65	Rail	11
Bellefonte - 2	P (B&W-1213)	65	Rail	
Yellow Creek - 1	P (CE-1287)	65	Rail	11
Yellow Creek - 2	P (CE-1285)	65	Rail	
Sequoyah - 1	P (W-1148)	65	kail	11
Sequoyah - 2	P (W-1148)	65	Rail	
Joseph M. Farley - 1	P (W-829)	52	Rail	9
Joseph M. Farley - 2	P (W-829)	52	Rail	

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Table 2 (Cont'd)

SHIPMENT CHARACTERISTICS AT PEAK YEAR

REACTOR	Reactor type, Supplier and Capacity[a](MWe)	No. of Assemblies Shipped per Year	Mode of Shipment	Total shipments per plt. site per Year
Wattsbar - 1	P (W-1177)	65	Rail	11
Wattsbar - 2	P (W-1177)	65	Rail	
Crystal River - 3	P (W-825)	52	Rail	4
Vogtle - 1	P (W-1121)	65	Rail	11
Vogtle - 2	P (W-1121)	65	Rail	
Shearon Harris - 1	P (W-915)	59	Rail	20
Shearon Harris - 2	P (W-915)	59	Rail	
Shearon Harris - 3	P (W-915)	59	Rail	
Shearon Harris - 4	P (W-915	59	Rail	
McGuire - 1	P (W-1180)	65	Rail	11
McGuire - 2	P (W-1180)	65	Rail	
Catawaba - 1	P (W-1180)	65	Rail	11
Catawaba - 2	P (W-1180)	65	Rail	
Perkins - 1	P (CE-1287)	65	Rail	16
Perkins - 2	P (CE-1287)	65	Rail	
Perkins - 3	P (CE-1287)	65	Rail	
Cherokee - 1	P (CE-1287)	65	Rail	16
Cherokee - 2	P (CE-1287)	65	Rail	
Cherokee - 3	P (CE-1287	65	Rail	
North Anna - 1	P (W-908)	59	Rail	20
North Anna - 2	P (W-907)	59	Rail	
North Anna - 3	P (B&W-907)	59	Rail	
North Anna - 4	P (B&W-907)	59	Rail	
Robinson - 2	P (W-740)	52	Rail	4
Virgil C. Summer - 1	P (W-900)	59	Rail	5
Edwin I. Hatch - 1	B (786)	140	Rail	10
Edwin I. Hatch - 2	B (795)	140	Rail	
Brunswick - 1	B (821)	140	Rail	10
Brunswick - 2	B (821)	140	Rail	

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Table 2 (Cont'd)

SHIPMENT CHARACTERISTICS AT PEAK YEAR

REACTOR	Reactor type, Supplier and Capacity[a](MWe)	No. of Assemblies Shipped per Year	Mode of Shipment	Total shipments per plt. site per Yr.
Phipps Bend - 1	B (1233)	200	Rail	14
Phipps Bend - 2	B (1233)	200	Rail	
Waterford - 3	P (W-1104)	65	Rail	5
Arkansas - 1	P (B&W-850)	59	Rail	10
Arkansas - 2	P (CE-912)	59	Rail	
Wolf Creek	P (W-1150)	65	Rail	5
Black Fox - 1	B (1150)	141	Rail	14
Black Fox - 2	B (1150)	141	Rail	
River Bend - 1	B (940)	180	Rail	13
River Bend - 2	B (940)	180	Rail	
Grand Gulf - 1	B (1254)	200	Rail	14
Grand Gulf - 2	B (1254)	200	Rail	

There are a total of 70 reactors (20 BWR's and 50 PWR's) at 33 sites.
Casks used are 2/4 for truck (2 PWR assemblies or 4 BWR assemblies per truck cask)
12/28 for rail (12 PWR assemblies or 28 BWR assemblies per rail cask)

[a]Key:
B - boiling water reactor (BWR)
P - pressurized water reactor (PWR)
B&W - Babcock and Wilcox
CE - Combustion Engineering, Inc.
W - Westinghouse Electric Corporation
All reactors without a reactor supplier code are General Electric Company reactors, the only boiling water reactor supplier.

Source: American Nuclear Society, 1980

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Table 3

DOMES AND LOCATIONS

Dome	State	Location
Rayburn's	LA	In Bienville Parish, 24 miles south of Ruston on U.S. 167 and 14 miles west on Louisiana 4
Vacherie	LA	On the Webster-Bienville parish line, 8 miles south of I-20 and 6 miles east of the U.S. 80 - I-20 interchange on Louisiana 531
Cypress Creek	MS	In Perry County, 22 miles southeast of Hattiesburg, south of U.S. 98 and east of Mississippi 29
Lampton	MS	In Marion County, 6 miles southeast of Columbia via U.S. 98 and county highways
Richton	MS	In Perry County, 27 miles southeast of Laurel, east of Mississippi 15 and the town of Richton
Keechi	TX	In Anderson County, 4 miles northwest of Palestine via U.S. 287 and Texas 19
Oakwood	TX	On the Freestone-Leon county boundary, 22 miles southwest of Palestine on U.S. 79

Sources: Dome locations: Office of Nuclear Waste Isolation, 1980b.

Highway information: American Automobile Association, 1980.

3. 2 ASSUMPTIONS

Assumptions concerning future technological and demographic conditions were made to facilitate the dome comparison process. These assumptions include:

- One repository will receive the entire waste stream from the commercial reactors in the Southern U.S. (NERC Regions 2,7, and 8) (Interagency Review Group, 1979).
- The national nuclear generation capacity in 1995 will be 175 GWe[a] (Office of Nuclear Waste Isolation, 1980a).
- The reactors for NERC regions 2, 7, and 8 (shown in Table 1) will be on-line and operating in 1993 (Interagency Review Group, 1979).
- The radiation dose from transportation was based on the projected peak spent fuel generation year (2004).
- The type of casks used will be 2/4 for trucks and 12/28 for rail. (See note, Table 2 for explanation).
- All shipments from reactors served by rail will be by rail; those from reactors without rail service will be by truck[a] (Office of Nuclear Waste Isolation, 1980a).
- Roads and railroads were assumed to be straight (U.S. Nuclear Regulatory Commission, 1977).

(a) Letter transmitted from M. W. Anthony of ONWI to L. G. Shappert of ORNL, April 30, 1980.

- Each repository site will have rail service. Where rail service does not currently exist, a spur will be built from the nearest rail line to the repository along the most reasonable route, as determined by visual inspection of U.S. Geological Survey quadrangle sheets. Such routes generally parallel main highways.

- The adequacy of railroad lines (height, width, length and weight limitations) to carry spent fuel shipments is as noted in Railway Line Clearances (National Railway Publication Co., 1980) according to prototypical vehicle dimensions (Office of Nuclear Waste Isolation, 1979).

- The adequacy of highways in regard to weight limitations is as indicated on maps designating highway classification published by the American Automobile Association (1980) and maps published by the various state highway departments. Federal-aid primary highways and all roads serving nuclear plants were assumed to have adequate weight limits for spent fuel shipment. Secondary and local highways were assumed to require upgrading.

- A point source was assumed for all dose calculations (U.S. Nuclear Regulatory Commission, 1977).

- For purposes of calculating doses to persons traveling on the same transportation route, interstate highways were assumed to be four-lane; all other highways were assumed to be two-lane

(U.S. Nuclear Regulatory Commission, 1977).

- Within Regions 2, 7, and 8, it was assumed that the average traffic volume will be 470 vehicles per hour (U.S. Nuclear Regulatory Commission, 1977).
- For general road traffic, average vehicle occupancy will be 2 persons per vehicle (U.S. Department of Energy, 1979).
- For general rail traffic, average train occupancy will be 200 persons per train (U.S. Department of Energy, 1979).
- Trucks will not travel in rush hour traffic (U.S. Nuclear Regulatory Commission, 1979).
- Average truck speed (excluding stop time) will be 50 miles per hour; the stop time for trucks will be 30 percent of total travel time (U.S. Nuclear Regulatory Commission, 1977).
- Average rail speed (excluding stop time) will be 25 miles per hour; the stop time for trains will be 60 percent of total travel time (U.S. Nuclear Regulatory Commission, 1977).
- Shipments will move through both rural and populated areas without route restrictions (Office of the Federal Register, 1980).
- The occurrence and extent of metropolitan areas (Ranally Metro Areas) and current population data were taken from the Rand McNally Commercial Atlas and Marketing Guide (Rand McNally & Co., 1980). Table 4 lists all metropolitan areas traversed by the study route.

Table 4

RANALLY METRO AREAS TRAVERSED BY STUDY ROUTES

Alabama

Anniston
Birmingham
Decatur
Florence/Sheffield
Gadsden
Huntsville
Mobile
Montgomery
Opelika
Tuscaloosa

Arkansas

Fort Smith
Little Rock
Pine Bluff
Texarkana
W. Memphis

Florida

Fort Pierce
Gainesville
Melbourne
Miami/Fort Lauderdale
Pensacola
Tallahassee

Georgia

Albany
Athens
Atlanta
Augusta
Columbus
Macon
Savannah

Kansas

none affected

Kentucky*

Ashland
Portsmouth

Louisiana

Alexandria
Baton Rouge
Lafayette
Lake Charles
Monroe
Morgan City
New Iberia
New Orleans
Shreveport

Mississippi

Gulfport/Biloxi
Hattiesburg
Jackson
Laurel
Meridian
Pascagoula
Vicksburg

North Carolina

Burlington
Charlotte
Durham/Chapel Hill
Greenboro/Highpoint
Goldsboro
Kannapolis
Raleigh
Salisburg
Wilmington

Ohio*

Cincinnati

Oklahoma

Muskogee
Tulsa

South Carolina

Columbia
Greenville
Rock Hill
Spartanburg

Tennessee

Chattanooga
Jackson
Knoxville
Memphis
Nashville

Texas

Beaumont
Dallas/Fort Worth
Freeport/Lake Jackson
Houston
Longview
Lufkin
Sherman/Denison
Texarkana

Virginia

Bristol
Charlottesville
Danville
Lynchburg
Newport News/Hampton
Richton
Roanoke

West Virgina*

Charleston
Huntington

*Although these states are outside of the southern region shown in Figure 1, they are traversed in some instances by applicable transportation routes.

Sources: Study routes: Office of Nuclear Waste Isolation, 1980a and letters transmitted from D. S. Joy of ORNL to J. T. Chappell of Bechtel, May 15 and 22, 1980; Metropolitan areas: Rand McNally & Co., 1980.

- Length of highways and railroad routes through Ranally Metro Areas was approximated by hand measurement on American Automobile Association (1980) maps and maps in the Commercial Atlas and Marketing Guide (Rand McNally & Co., 1980).
- For purposes of population projections, the 1975 and 2000 period 10-year growth rates by state (U.S. Bureau of the Census, 1979) were assumed valid for the 1980 to 2000 projection period.
- The populations of the peak spent fuel generation year (2004) were assumed to be equal to the projected year 2000 populations.
- The 1980 to 2000 period growth rate for each Ranally Metro Area was assumed to be equal to the growth rate for the state as a whole during that period. The increase of population densities within the Ranally Metro Area was assumed to be propositional to state population growth rates.
- Where Ranally Metro Areas cross state lines, the highest growth rate of the two states was assumed as the growth rate for the entire metropolitan area.

3.3 TRANSPORTATION ROUTES

Transportation routes from the various reactors in NERC Regions 2, 7, and 8 to each of the seven domes were developed and provided for this study by ORNL.(a) At the 27 sites (54 reactors) accessible by rail, spent fuel was assumed to be transported by rail. Only six reactor sites involving 16 reactors (Browns Ferry 1, 2, and 3; Hartsville 1, 2, 3, and 4; Oconee 1, 2, and 3; St. Lucie 1 and 2; Surry 1 and 2; and Turkey Point 3 and 4) do not have rail access. The spent fuel from these reactors was, therefore, assumed to be shipped by truck. Results of the ORNL computer models were a given input to this report.(b)

3.3.1 Truck Routes

Truck routes from reactors to repository sites were calculated by ORNL Using the COMPU.MAP program (Logistics Systems, Inc., 1980). The computer program was developed by Logistics Systems, Inc., in Wellesley, Massachusetts. The basic parts of the COMPU.MAP program are the highway data base, which is essentially a computerized road atlas, and a "least resistance" route selection algorithm.

The data bases consist of a series of highway segments called links, and the points of interconnection of the links, called nodes. There are approximately 12,500 links and 9,500 nodes in the national data base, which represent all interstate and U.S. highways, and the principal state highways. Although this data base presents a useful representation

(a) Letters transmitted from D. S. Joy of ORNL to J. T. Chappel of Bechtel, May 15 and 22, 1980.

(b) Letter transmitted from M. W. Anthony of ONWI to L. B. Shappert of ORNL, April 30, 1980.

of the U.S. highway system, not all highways and towns are included.

In order to calculate an optimum route, a performance criterion (objective function) was defined by ORNL. The objective function used in the ORNL analysis was the "most practical" route defined as a combination of driving time and distance, with driving time assigned a relative weighting of 70 percent of the total function, and distance assigned a relative weighting of 30 percent. Because of the higher relative weighting of driving time vs. distance, this criterion tended to restrict shipment to high-speed highways, especially interstate and major U.S. highways. A detailed route description supplied by ORNL for each route specifies origin and destination, highways used, mileage along each highway, and total mileage.

Because not all towns are included in the COMPU.MAP data base, the nodes nearest the reactors and salt domes were selected as terminal points for the computer analysis. The segments from the computer analysis terminal points to the actual reactors and domes were calculated by hand.

Table 5 shows a typical output of the COMPU.MAP program for the route from the node nearest Lampton Dome to the node nearest Browns Ferry, reading from dome to reactor. The average speed of transportation was assumed to be 50 miles per hour, excluding stops. This is consistent with average truck speed achievable over long distances with two drivers. The truck stop time, including rest, refueling and all other stops, is

Table 5

SAMPLE TRUCK ROUTE COMPU.MAP OUTPUT
FROM BROWN'S FERRY REACTOR TO LAMPTON DOME, MS

05/14/80

(N) COLUMBIA MS TO (SE) ATHENS AL

TAKE ROUTE		JUNCTION			MILE-AGE	TIME (HRS)
			S13, S35	NORTH OF COLUMBIA	MS 0	:00
S13	2 MILES TO	U98, S13		S EAST OF COLUMBIA	MS 2	:03
U98	29 MILES TO	I59, X13		WEST OF HATTIESBURG	MS 31	:45
I59	108 MILES TO	I59, U80		NORTH OF CUBA	AL 139	3:04
U80	1 MILES TO	U11, U80		N EAST OF CUBA	AL 140	3:05
U11	17 MILES TO	U11, S28		N EAST OF LIVINGSTON	AL 157	3:30
S28	1 MILES TO	I20, S28		NORTH OF LIVINGSTON	AL 158	3:32
I20	108 MILES TO			BIRMINGHAM	AL 266	5:43
U31	20 MILES TO	I65, U31		S WEST OF WARRIOR	AL 286	6:12
I65	70 MILES TO	I65, U72		S EAST OF ATHENS	AL 356	7:36

STATE MILEAGE
MS 138
AL 218

Note: Table reads from dome to reactor.

Source: Letter transmitted from D. S. Joy of ORNL to J. T. Chappell of Bechtel, May 15, 1980.

normally about one third of total travel time (U.S. Nuclear Regulatory Commission, 1977).

3.3.2 Rail Routes

The ORNL rail routing program was developed in order to select likely transportation routes for rail shipments of radioactive waste and related commodities. The data base used by ORNL in their program was based on the Federal Railroad Administration data base that contains all active rail lines in the United States. For use in routing spent fuel shipments, this large data base was condensed by the removal of all spur lines. Rail routing was computed between the reactor and the node nearest the dome; as with the truck routes, the distance from the nearest node to the dome was calculated by hand.

The ORNL rail routing model locates the path of "least resistance" between source and destination, based in this case on distance and class of railroad. The shortest distance path is not necessarily the most favorable. Freight tends to move along main lines, using branch lines only in the vicinity of the source or destination. For each type of rail line, the "resistance" was defined as the distance times a penalty factor. The penalty factors are: A-main lines = 1.0; B-main lines = 1.1; A-branch lines = 1.7; B-branch lines = 3.0; and other lines = 500.0. Using the penalty

factors, the ORNL program would select an A-main line over a B-main line, unless the distance along the A-main line is more than 10 percent greater than that along the B-main line.

More than one rail line will often be involved in a shipment. Interchanges between rail lines can be made only at certain nodes, identified in the ORNL data base. There may be several viable interchange points between two railroads, but most ORNL routes minimized the number of interchanges. A shipment requiring several rail line interchanges is inefficient because there are significant delays at interchange points. The originating railroad will therefore tend to keep the shipment on its system as long as possible. This was simulated in ORNL's rail routing model by multiplying all resistances on the original system by 0.8, and by adding an additional resistance of 300 to the objective function for each interchange.

The computer model determined a route from each reactor to each dome, and a detailed computer printout was provided by ORNL for each route. The printouts list each node along the shipment route, the rail line being used, and the distance from the previous node, reading from dome to reactor. At the end of the printout a summary gives the total distance traveled, the distance on each rail line, and the distance in each state.

A typical rail route as developed by the ORNL program from the node nearest Lampton Dome to the node nearest Sequoyah reactor is shown in

Table 6.

Table 7 shows rail lines serving repositories and reactors used in the ORNL model.

3.3.3 Adequacy of Railroads and Roads

Railroad routes to which shipments have been assigned were verified for adequacy using Railway Line Clearance (National Railway Publication Company, 1980). This document lists clearances and weight limitations for all railroads in North America, as furnished by the railroads. Casks and railroad car conceptual designs are based on an estimated gross weight of 216,000 pounds to 273,000 pounds per rail car, with a maximum weight (based on standard railroad limits) of 263,000 pounds for unlimited use of the rail car (Office of Nuclear Waste Isolation, 1979).

All rail lines to which shipments have been assigned will meet the low-range 216,000-pound gross weight limit. With two exceptions, all other lines will meet the 263,000-pound unlimited use range. The exceptions are

- A 27.8-mile link on the Illinois Central Gulf (ICG) Railroad Company system, connecting Columbia, Mississippi, (the nearest rail node to Lampton Dome) with Silver Creek and the ICG through-route, having a 220,000-pound limit.

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Table 6

SAMPLE RAIL ROUTE ORNL COMPUTER OUTPUT
FROM SEQUOYAH REACTOR TO LAMPTON DOME, MS

NR	FRA NUM	RR	NODE NAME	STATE	POTENTIAL	VIA LINK NUM	LENGTH	MLC	SIG	SPEED	TRAF	NTRKS	OWNER
3	8942	ICG	COLUMBIA	MS	869.1	4218	27.8	4	0	99	1	1	
3	8960	ICG	SILVER CREEK	MS	757.9	4225	54.0	3	0	90	2	1	
3	8963	ICG	HATTIESBURG	MS	655.3	TRANSFER							
27	8963	SOU	HATTIESBURG	MS	355.3	4229	29.0	1	1	60	4	1	
27	8970	SOU	LAUREL	MS	331.5	4182	54.0	1	1	60	4	1	
27	8887	SOU	MERIDIAN	MS	287.2	4052	19.0	1	2	60	5	1	
27	8614	SOU	CUBA	AL	271.7	4051	8.0	1	2	60	5	1	
27	8639	SOU	YORK	AL	265.1	4060	25.0	1	2	60	5	1	
27	8640	SOU	BOLIGEE	AL	244.6	4061	19.0	1	2	60	8	1	
27	8641	SOU	AKRON	AL	229.0	4049	12.0	1	2	60	5	1	
27	8611	SOU			219.2	4050	13.0	1	0	60	5	1	
27	8754	SOU	TUSCALOOSA	AL	208.5	4080	27.0	1	2	60	3	1	
27	8651	SOU	WOODSTOCK	AL	186.4	4079	42.7	1	2	60	3	1	
27	8739	SOU	BIRMINGHAM	AL	151.4	4084	25.0	1	2	60	4	1	
27	8663	SOU			130.9	4085	37.0	1	1	60	4	1	
27	8797	SOU	GADSDEN	AL	100.5	3682	58.0	1	1	60	8	1	
27	7853	SOU			53.0	3346	24.0	1	1	60	4	1	
27	7225	SOU	WAUHATCHIE	TN	33.3	3345	6.0	1	2	60	4	2	
27	7235	SOU	CHATTANOOGA	TN	28.4	3361	34.6	1	2	60	6	1	
27	7231	SOU	DAISY	TN	0.0								

LENGTH OF PATH IS 819.1 MILES

MILEAGE SUMMARY BY RAILROAD

ICG	81.8
SOU	433.3

MILEAGE SUMMARY BY STATE

AL	296.7
GA	24.0
MS	183.8
TN	40.6

Note: Table reads from dome to reactor.

Source: Letter transmitted from D. S. Joy of ORNL to J. T. Chappell of Bechtel, May 22, 1980.

Table 7

RAIL LINES SERVING REACTORS AND REPOSITORY SITES

Reactors	Railroads
South Texas Project	MP
Comanche Peak	ATSP
Allens Creek	SP
Bellefonte	SOU
Yellow Creek	SOU
Sequoyah	SOU
Watts Bar	SOU
Joseph M. Farley	SOU
Crystal River	SCL
Vogtle	SOU
Shearon Harris	SOU
McGuire	SCL
Catawaba	SOU
Perkins	SOU
Cherokee	SOU
North Anna	CO
Robinson	SCL
Virgil C. Sumner	SOU
Edwin I. Hatch	SOU
Brunswick	SCL
Phipps Bend	SOU
Waterford	MP
Nuclear One	MP
Wolf Creek	MP
Black Fox	MP
River Bend	ICG
Grand Gulf	ICG

Repository Sites	Railroads
Louisiana	KCS
Mississippi	ICG
Texas	MP

Railroad key:

SOU	=	Southern
MP	=	Missouri Pacific
SCL	=	Seaboard Coast Line
ICG	=	Illinois Central Gulf
SP	=	Southern Pacific
ATSF	=	Atchinson, Topeka and Santa Fe
CO	=	Chesapeake and Ohio
KCS	=	Kansas City Southern

Source: Letter transmitted from D. S. Joy of ORNL to J. T. Chappell of Bechtel, May 22, 1980.

- A Louisville and Nashville Railroad Company link of approximately 35 miles between Chattanooga, Tennessee, and Stevenson, Alabama, connecting Oakwood and Keechi Domes, Texas, with several reactors in the southeastern portion of Region 7, having a 256,000-pound limit.

These two lines would require upgrading if they are to be used. Dimensional limitations according to American Association of Railroads specifications (Office of Nuclear Waste Isolation, 1979) can be met on all proposed lines.

No domes have existing rail service. Estimates for the length of track required to reach the potential repository sites are:

Keechi Dome, Texas	6-7 miles
Lampton Dome, Mississippi	5-6 miles
Cypress Creek Dome, Mississippi	4-5 miles
Vacherie Dome, Louisiana	3-4 miles
Rayburn's Dome, Louisiana	3-4 miles
Richton Dome, Mississippi	1-2 miles
Oakwood Dome, Texas	1-2 miles

Table 8 indicates allowable gross vehicle weights in the states under consideration for truck shipment. They range from 73,280 pounds to 80,000 pounds for interstate highways and from 73,280 pounds to 92,4000

Table 8

GROSS VEHICLE WEIGHT LIMITS, BY STATE

State	Gross Vehicle Weight - Pounds	
	Interstate	Primary Highways
Alabama	80,000	92,400
Arkansas	73,280	73,280
Florida	80,000	80,000
Georgia	80,000	80,000
Kansas	80,000	85,000
Louisiana	80,000	80,000
Mississippi	73,280	73,280
North Carolina	79,800	79,800
Oklahoma	80,000	90,000
South Carolina	80,000	88,000
Tennessee	73,280	73,280
Texas	80,000	80,000
Virginia	79,800	79,800

Source: Office of Nuclear Waste Isolation, 1979.

pounds for primary U.S. or state highways. Conceptual design vehicles for shipment of spent fuel casks have maximum gross weights of 73,280 pounds so that they may be used nationwide (Office of Nuclear Waste Isolation, 1979). Examination of the routes selected by the COMPU.MAP program indicates that all shipments are scheduled for highways which are part of the Federal-aid primary highways system. These include both Federal- and state-designed highways. For end-portions of shipments unassigned by computer, there are four domes not served by primary highways. The four domes are:

Rayburn's Dome, Louisiana	Approximately 14 miles on Louisiana 4, a Federal-aid secondary highway
Vacherie Dome, Louisiana	Approximately 7 miles on Louisiana 531, a Federal-aid secondary highway and 1 mile on a graveled and graded local road
Cypress Creek Dome, Mississippi	Approximately 6 miles on Mississippi 29, a bituminous highway designed for light traffic

Lampton Dome, Mississippi	Approximately 5 miles on a Federal-aid secondary highway

It is expected that these highways would require rebuilding to handle heavy construction equipment, personnel transport, and spent fuel transport.

At the reactor end, it was assumed for purposes of this preliminary study that highways sufficient for power plant construction and operation traffic meet or will meet the 73,280-pound load limit.

4.0 DOSE CALCULATIONS

4.1 POPULATION ANALYSIS

Transportation routes selected by the ORNL models (described in Section 3.3) were plotted by hand on maps showing Ranally Metro Areas (Rand McNally & Co., 1980). Route distances through the metropolitan areas were measured and the 1980 population estimate and land area for each metropolitan area was noted. Based on state growth rates (U.S. Bureau of the Census, 1979), an approximate year 2000 population was projected for each metropolitan area. The average metropolitan population densities were determined for the existing areas, and approximate year 2000 population density was calculated for each individual link as follows:

$$PD = \frac{P_o \, G}{A} \qquad (3\text{-}1)$$

where

- PD = estimated area population density in year 2000 (persons per square mile)
- P_o = estimated area population in 1980 (persons)
- G = 20-year growth rate of state population, derived from growth rates provided by the U.S. Bureau of the Census (1979)
- A = land area (square miles)

Population density for each link and the number of miles per link were recorded. The same procedure was followed for rural (non-metropolitan)

areas. Where origins and destinations in the computer models were not the actual facility locations, small adjustments were made by hand.

4.2 RADIATION DOSES DURING SPENT FUEL TRANSPORT

Radiation doses were calculated using procedures developed by the U.S. Nuclear Regulatory Commission (1976 and 1977). The procedures are described in this section. The shipment parameters used for the calculations are given in Table 9.

A point source at the center of the cask was assumed for all dose calculations. This is a reasonable assumption due to the distances of typical exposed individuals from the source (U.S. Nuclear Regulatory Commission, 1977). The dose rate at a given distance from a point source is given by:

$$D_1 = \frac{K B_1 e^{-ud}}{d^2} \qquad (3\text{-}2)$$

where

D_1 = dose rate at a distance d (mrem/hr)

K = dose rate factor (mrem-ft^2/hr)

B_1 = Berger buildup factor in air (dimensionless)

$B(d) = 0.0006d + 1$

u = absorption coefficient for air (0.00118 ft^{-1})

d = distance from source (ft)

Table 9

SHIPMENT PARAMETERS FOR CALCULATION OF RADIATION DOSES

	Truck	Train
Average speed (mi/hr)	50	25
Duration of stops (hr)	30% of total travel time	60% of total travel time
One way traffic count (per hr)	470	0.21 (5 per day)
Number of crew	2	5
Average number of passengers in other vehicles on transport route	2	200
Number of packages per shipment	1	1
Number of shipments per year	588	295
Type of casks used	2/4	12/28
Average distance between crew and package (ft)	10	500
Dose rate to crew in cab (mrem/hr)	2	2.9×10^{-6}

Sources: Number of passengers per vehicle: Sandia Laboratories, 1978

All other parameters: U.S. Nuclear Regulatory Commission, 1977

4.2.1 Dose to Surrounding Population While Vehicle is Moving

An expression for the total integrated dose absorbed by an individual at distance d from the path of a moving radioactive shipment with dose rate factor K passing along a straight road at velocity V can be derived from Equation 3-2 and is given by:

$$D(d) = \frac{2K}{V} \int_{d}^{\infty} \frac{e^{-ur} B(r)}{r(r^2-d^2)^{1/2}} dr \qquad (3\text{-}3)$$

where

D(d)	=	total integrated dose (mrem)
K	=	dose rate factor (mrem-ft^2/hr)
V	=	shipment speed (ft/hr)
B(r)	=	Berger buildup factor in air (dimensionless)
		$B(r) = 0.0006r + 1$
d	=	shortest distance of individual receptor from source (ft)
r	=	distance of receptor from source at any time (ft) See Figure 2 for explanatory diagram.

The integral in Equation 3-3 takes into account the fact that the dose buildup is symmetrical as the source approaches and recedes from the receptor, and that the dose rate increases as the source moves from distance ∞ to distance d. Figure 2 diagrams the geometry that determines the dose for any individual. The population dose can be calculated by dividing the area from reactor to dome in sectors of length L and with d on both sides of the roadway as diagrammed in Figure 3. The smallest distance d between an exposed individual and the shipment centerline was approximated at 100 feet, and the maximum distance from the centerline

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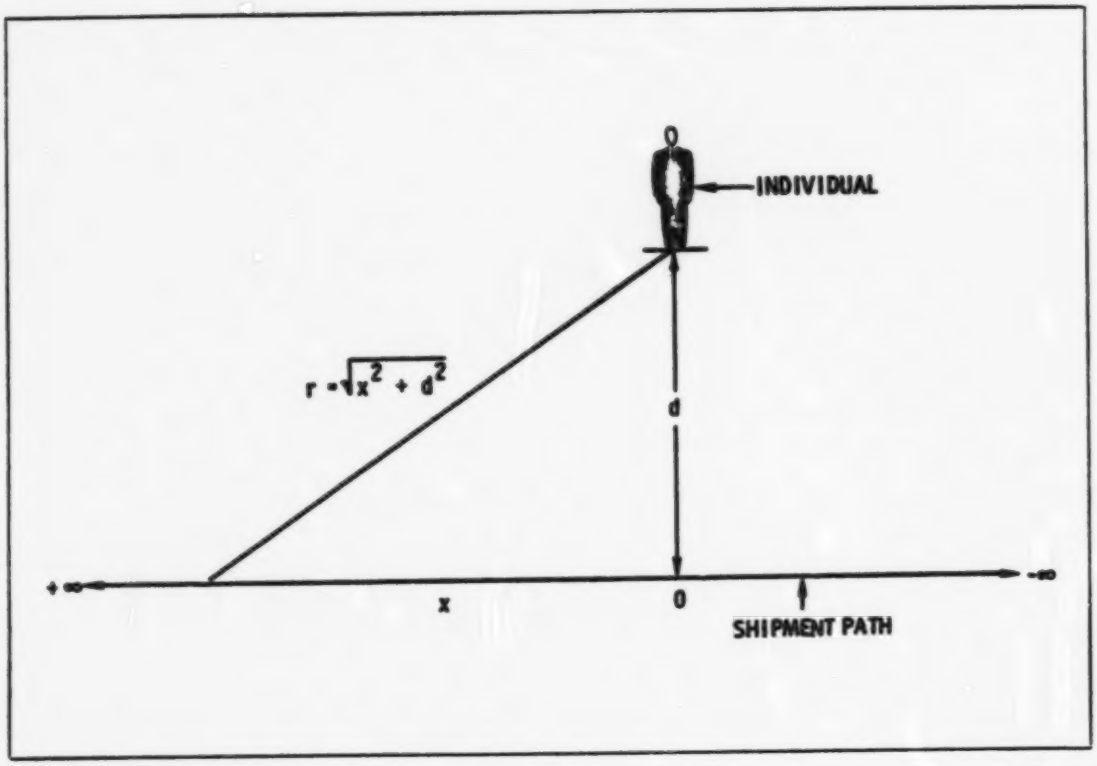
Figure 2

GEOMETRY FOR INDIVIDUAL DOSE CALCULATIONS



Source: Sandia Laboratories, 1978.

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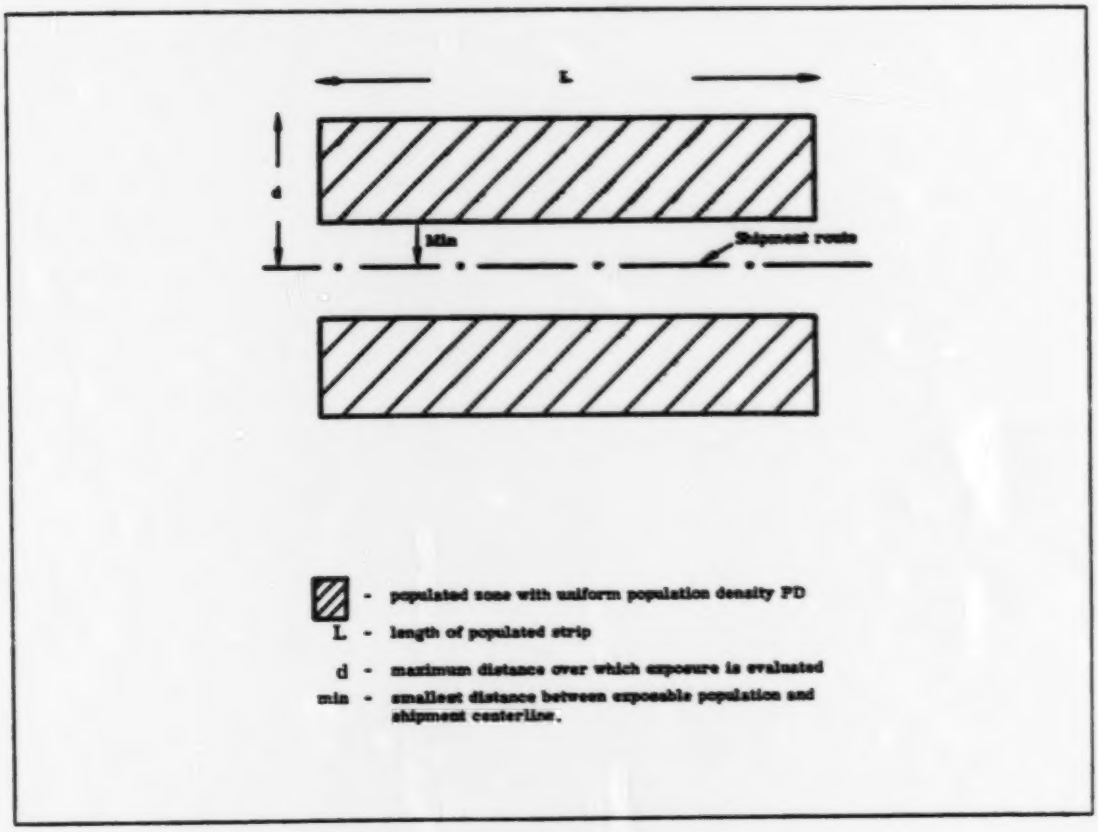
Figure 3

DOSE TO PERSONS LIVING ALONG THE TRANSPORT LINK


L
d
Min
Shipment route
- populated zone with uniform population density PD
L - length of populated strip
d - maximum distance over which exposure is evaluated
min - smallest distance between exposable population and shipment centerline.

Source: U.S. Nuclear Regulatory Commission, 1977.

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over which the exposure was calculated is 2,600 feet, i.e. approximately one-half mile on each side of the shipment route (U.S. Nuclear Regulatory Commission, 1977). Large casks of spent fuel were assigned a dose rate factor of 1000 mrem-ft^2/hr and a transport index (the dose 3 feet from the source) of 1.0 mrem/hr (U.S. Nuclear Regulatory Commission, 1977). The equation used to calculate the annual dose to the population along the transport route is as follows:

$$\text{Dose}_{(pop)} = 3.47 \times 10^{-10} (K) \sum (PPS)(SPY)(FMPS)\left(\frac{PD}{V}\right) \qquad (3\text{-}4)$$

where

$\text{Dose}_{(pop)}$ = dose to surrounding population in person-rem/year

K = dose rate factor (1000 mrem-ft^2/hr-package)

PPS = packages per shipment (1 cask per shipment)

SPY = shipments per year

FMPS = distance per shipment segment (miles)

PD = population density (person/mi^2)

V = average speed (mi/hr)

3.47×10^{-10} = conversion factor = $4\ (2.42)\left(\frac{\text{rem}}{1000\ \text{mrem}}\right)\left(\frac{\text{mi}}{5280\ \text{ft}}\right)^2$.

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4.2.2 Doses to Travelers on Transport Link

Figure 4 shows a truck carrying radioactive material traveling at velocity V along with other vehicles in the same lane. There are two separate doses to be computed for both truck and train:

- The dose to persons traveling in the opposite direction
- The dose to persons traveling in the same direction.

4.2.2.1 Dose to persons traveling in the opposite direction

With both the shipment truck and the oncoming traffic moving at velocity V (mi/hr), the dose received by an individual in an oncoming vehicle may be computed by assuming that the oncoming vehicle is at rest as it passes by the shipment at a velocity of 2V. Thus the average integrated dose received by a person in an oncoming vehicle passing the truck at a distance d can be formed by a simplification of Equation 3-3.

$$D = \frac{2K}{2(V)} I(d) \qquad (3\text{-}5)$$

The value of the integral I(d) depends on the distance (d) of closest approach, which in turn depends on the type of road. The values for I(d) are given in Table 10. Under the assumptions given in Section 3.2 the equation for the annual population dose to persons traveling in a direction opposite to the shipment is:

$$\text{Dose}_{(opp)} = Q(K) \sum (PPS)(SPY)(FMPS)(P)F \qquad (3\text{-}6)$$

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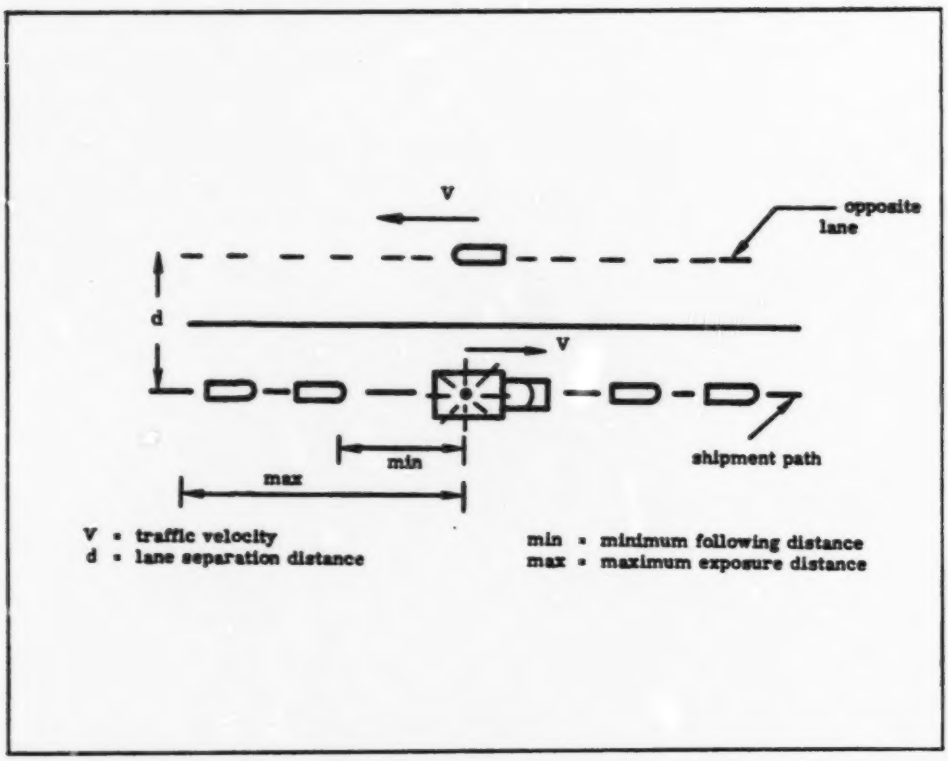
Figure 4

DOSE TO PERSONS IN VEHICLES SHARING THE TRANSPORTATION LINK WITH THE SHIPMENT



Source: U.S. Nuclear Regulatory Commission, 1977.

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Table 10

VALUES OF I(d) FOR USE IN EQUATION 3-5 DOSE CALCULATION

	d(ft)	$I(d)(ft^{-1})$
A. Vehicles traveling the opposite direction on:		
Interstate highways	50	2.9×10^{-2}
2-lane highways	10	1.5×10^{-1}
Railroads	10	1.5×10^{-1}
B. Vehicles traveling the same direction on:		
Interstate highways	100	8.0×10^{-3}
2-lane roads	10	9.7×10^{-2}
Railroads	10	9.7×10^{-2}

Source: U.S. Nuclear Regulatory Commission, 1977.

where

$Dose_{(opp)}$ = dose in person-rem/yr to perons traveling in the opposite direction

$F = F_{int} \frac{N_s I_{int}}{(V)^2} + \frac{F_L N_s I_L}{(V)^2}$

$Q = (10^{-3} \frac{rem}{mrem}) (\frac{1 mi}{5280 ft}) = 1.89 \times 10^{-7}$

K = dose rate factor = 1000 mrem-ft^2/hr-package

PPS = packages per shipment

SPY = shipment per year

FMPS = distance per shipment segment (miles)

F_{int}, F_L = fraction of travel on interstate, 2-lane highways, respectively

Ns = traffic count, average number of cars per hour

I_{int}, I_L = integral at interstate, 2-lane road values, respectively

V = average velocity (mi/hr)

P = average number of persons per vehicle.

4.2.2.2 Dose to persons traveling in the same direction as the shipment

On the average, vehicles carrying spent fuel travel at the same

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velocity as the rest of the traffic. Thus, vehicles traveling in the same direction as the shipment can be modeled as a static set of vehicles at a fixed point from the shipment. As in the case of persons traveling in the opposite direction, traffic count and velocity will depend on the population density, and the distance of closest approach depends on the type of road. Using the assumptions listed in Section 3.2, the following expression can be obtained for the annual doses received by persons traveling in the same direction as the shipment:

$$\text{Dose}_{(\text{same})} = Q'(K)\sum(\text{PPS})(\text{SPY})(\text{FMPS})(P)F \qquad (3\text{-}7)$$

where

$\text{Dose}_{(\text{same})}$ = dose in person-rem/yr to persons traveling in the same direction as the shipment

$F = \frac{F_{int}\, N_s\, I_{int}}{(V)^2} + \frac{F_L\, N_s\, I_L}{(V)^2}$

Q'* = $2 \times 10^{-3} \left(\frac{\text{rem}}{\text{mrem}}\right)\left(\frac{1\text{ mi}}{5280\text{ ft}}\right) = 3.79 \times 10^{-7}$

K = 1000 mrem ft^2/hr-package

PPS = package per shipment

---

* The factor of 2 takes into account vehicle ahead and behind the shipment.

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SPY	=	shipments per year
P	=	average number of persons per vehicle
F_{int}, F_L	=	fraction of travel on interstate, 2-lane highways, respectively
N_s	=	traffic count, average number of cars per hour
I_{int}, I_L	=	integral at interstate, 2-lane highways, respectively
V	=	average velocity (mi/hr)
FMPS	=	distance per shipment segment (miles)

4.2.3 Dose to Crew

The annual dose to crew is obtained directly from Equation 3-2 by using an average source-to-crew characteristic distance (d) for each transport mode:

$$Dose_{(crew)} = Q'' \sum (Nc)(Dr)\Delta T_{(ship)} \qquad (3\text{-}8)$$

where

$Dose_{(crew)}$	=	dose to crew in person-rem/year
Q"	=	10^{-3} $(\frac{rem}{mrem})$
Nc	=	number of crew aboard
$\Delta T_{(ship)}$	=	time required per shipment segment $(\frac{FMPS}{V})$ in hours
FMPS	=	distance per shipment segment (miles)

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V = average velocity (mi/hr)

Dr = dose rate per package (mrem/hr) in cab

The dose to the truck crews calculated using the above formula and the conservative parameters specified by the U.S. Nuclear Regulatory Commission (1977) exceeded the maximum allowable dose specified by the U.S. Atomic Energy Commission (1974). Therefore, it was assumed for the remainder of the analysis that additional cab shielding would be provided to limit the truck crew's dose to the U.S. Atomic Energy Commission's allowable dose rate of 2 mrem/hr.

4.2.4 Dose to Population During Shipment Stops

When the shipment stops for crew change, meals, or refueling, persons in an annular area around the stop point may be exposed. The dose is obtained by integrating a form of Equation 3-3.

$$Dose_{(stop)} = Q'''(K)\sum(PPS)(SPY)(\Delta T_{(stop)})(PD) \qquad (3\text{-}9)$$

where

$Dose_{(stop)}$ = dose in person-rem/yr to persons near shipment stops

$Q''' = 9.78 \times 10^{-10} \left(\frac{\text{rem-mi}^2}{\text{mrem-ft}^2}\right)$

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K	=	1000 mrem-ft^2/hr
PPS	=	packages per shipment
SPY	=	shipments per year
$\Delta T_{(stop)}$	=	stop time for each segment (hours)
PD	=	population density (persons/mi^2)

5.0 RESULTS

The procedures outlined in Section 4 were followed for calculating conservative radiation doses from normal transportation of spent fuel from each reactor to each repository dome. It was assumed that only one repository dome will be developed in the region and that all reactors in the region will ship spent fuel to the same dome. The radiation doses during normal transportation of spent fuel from all the reactors to a dome were summed. Table 11 shows the comparative doses for each repository site by component. Lines 1 through 3 show radiation doses to the population during normal transportation of spent fuel by truck from six reactor sites. The highest annual dose will be received by the truck crews; the dose to the truck crew, however, could be reduced orders of magnitude by additional shielding as long as the weight limit for the truck is not exceeded. Lines 4 through 6 show the radiation doses to the population during normal transportation of spent fuel by rail from the remaining reactor sites in the region. The highest annual dose during rail transport will be received by the population surrounding the train route.

Line 7 in Table 11 shows the sum of lines 2 through 6. This is the total dose less the dose to the truck crew. Line 8 shows the total radiation dose to the population, including that to the truck crew, during normal transportation of spent fuel from all reactors in the region. The data are presented in this manner to illustrate how the dose to the truck crew dominates the total dose. Total doses are lowest for repository

Table 11

COMPARATIVE RADIATION DOSES FROM NORMAL TRANSPORT OF SPENT FUEL TO SEVEN SALT DOMES
(person-rem/yr)

		Mississippi			Texas		Louisiana	
		Lampton	Richton	Cypress Creek	Oakwood	Keechi	Rayburn's	Vacherie
1.	Dose to truck crew	41	38	40	63	62	51	51
2.	Dose to other road traffic	3	3	2	4	5	4	4
3.	Dose to persons within 1/2 mile of truck route	2	2	2	3	2	2	2
4.	Dose to train crew	0.6	0.7	0.5	0.8	0.8	0.8	0.8
5.	Dose to other traffic	0.5	0.5	0.5	0.7	0.7	0.6	0.6
6.	Dose to persons within 1/2 mile of train route	2	2	2	3	3	3	3
7.	Dose to population excluding truck crew (lines 2 through 6)	8	8	8	12	12	11	11
8.	Total dose to population	49	46	48	75	74	62	62
9.	Dose per average truck shipment	0.08	0.073	0.075	0.12	0.12	0.097	0.097
10.	Dose per average train shipment	0.007	0.007	0.006	0.012	0.012	0.012	0.012

dome sites located in Mississippi and highest for those in Texas. The calculated values presented in this report are not absolute; and, given the assumptions of this study, total doses to all seven domes are comparable.

Because of the conservative approach and simplifying assumptions used in this report, the results should not be compared to other analyses without an appreciation of precision and accuracy.

Table 12 provides estimated doses to an individual in the United States from all sources in the year 2000. Table 12 also lists integrated annual doses to the total population. These data are provided for comparative purposes (U.S. Nuclear Regulatory Commission, 1977).

Table 13 lists the total population along all transportation routes to each dome, and compares the dose to these persons from background radiation to the dose received from normal spent fuel transportation. It can be seen (line 4) that transportation-related doses will constitute an increase of only 0.004 to 0.005 percent of the dose such persons normally receive.

The U.S. Nuclear Regulatory Commission limits radiation dose from all sources to the general public to 0.5 rem/year/person above background radiation levels (U.S. Atomic Energy Commission, 1974). The National Commission on Radiological Protection, however, recommends limiting this dose to 0.17 rem/year/person (Eichholz, 1977). The total dose from transportation of spent fuel is a small percentage of either limit. For example,

Table 12

ESTIMATES OF ANNUAL WHOLE-BODY DOSES
IN THE UNITED STATES

Source	Average Annual Dose per Person* (mrem)	Integrated Annual Population Dose** (10^6 person-rem)
Cosmic rays	44	9.7
Terrestrial radiation		
External	40	8.8
Internal	18	4.0
Fallout	4	0.9
Nuclear power	0.4***	0.09
Medical/Dental		
Diagnostic X-rays	72+	15.8
Radiopharmaceuticals	1	0.2
Occupational	0.8	0.2
Miscellaneous	2	0.4
Total:	182.2	40

*The numbers shown are average values only. For given segments of the population, doses considerably greater than these may be experienced.
**Based on U.S. population of 220 x 10^6.
***Estimated for the year 2000.
+Based on the abdominal dose.

Source: U.S. Nuclear Regulatory Commission, 1977.

Table 13

COMPARISON OF RADIATION DOSE DUE TO NORMAL TRANSPORTATION OF SPENT FUEL WITH DOSE DUE TO BACKGROUND RADIATION

	Lampton	Richton	Cypress Creek	Oakwood	Keechi	Rayburn's	Vacherie
1. Total population considered during transportation (1 year)	6,300,000	5,800,000	5,900,000	8,100,000	8,000,000	9,200,000	9,100,000
2. Dose to population during transportation due to background radiation $\frac{\text{person-rem}}{\text{year}}$ (@182 mrem/year/person)	1,200,000	1,100,000	1,100,000	1,500,000	1,500,000	1,700,000	1,700,000
3. Total dose due to normal transportation of spent fuel $\frac{\text{person-rem}}{\text{year}}$	49	46	48	75	74	62	62
4. Dose due to transportation as a percent of background radiation	0.004	0.004	0.004	0.005	0.005	0.004	0.004

Source: Background radiation: U.S. Nuclear Regulatory Commission, 1977.

the highest total dose, 75 person-rem/year (12 person-rem/year without truck crew dose), is only 0.018 (0.003) percent of the allowed limit of 0.5 rem/year (403,000 person-rem/year). Thus, the total dose from transportation of spent fuel is well below allowed limits. The number of shipments each crew member takes will be controlled to ensure that he or she does not receive more than the annual allowable dose of 5 rem.

In addition to the negligible health effects, transportation of spent fuel will involve a potential for vehicular accident deaths. There will be an annual total of 588 truck shipments with maximum total round-trip distance of 1,042,000 miles to Oakwood Dome. The National Safety Council (1978) reports traffic fatality statistics of 3.38 deaths per 100,000,000 miles. This includes all automobile and truck trips, and thus can be expected to overstate the accident rate for special vehicles that would be traveling primarily on interstate highways and during weekdays only (U.S. Nuclear Regulatory Commission, 1977). At this conservative rate, there will be an additional 0.24 highway accident deaths each year, or about one death every 4 years.

In contrast to the relatively high (about 50,000 deaths per year) fatality rate associated with all highway traffic in the United States, there are about 1,700 deaths annually associated with all forms of railroad accidents, or one fatality per 540 million miles (National Safety Council, 1978). Spent fuel shipment will entail 580,000 miles of rail shipment per year, consisting of 295 round trips. Based on these statistics, no rail fatalities are predicted during the life of the repository.

6.0 RECOMMENDATIONS FOR ADDITIONAL STUDY

This report provides a preliminary comparison of radiation doses due to transport of nuclear wastes from reactor to dome under normal shipment conditions. The comparison was based on the computer model output received from ORNL, and on other facts and assumptions about spent fuel assemblies, shipment, and repositories. Within this framework, it appears that the normal condition total dose is not a principal consideration for repository site selection.

As the NWTS program proceeds and knowledge concerning the total program increases, more detailed transportation studies will be required for the dome or domes selected for further study. Although more exact information will undoubtedly modify the numerical data presented here, it is unlikely that the general conclusion that there is no significant dose due to transportation will change because the dose commitment is so low. However, based on nuclear industry experience (Maxey, 1978), it is likely that transportation routing will continue to be a siting issue, not for technical reasons as much as for reasons of public concern. When actual repository sites are chosen, studies of the following types may further add to assuring general as well as nuclear safety:

- Accident scenarios. Although any two given routes may affect essentially the same number of people, one route may pass through large urban areas, with consequently different impacts in case of an accident. Alternative dome locations and alternative transportation routes should be tested to minimize potential accident impacts.

- Multiple routings. The existing models selected a single route from each reactor site to each repository site. Alternatively, multiple routes could be used that would spread the perceived risk among different populations, and decrease the dose any one individual would receive.

- Minimization of trips. Present cask and vehicle configurations are predicated on ability to ship via commonly available rail and truck routes. Trips might be minimized by transporting heavier loads on selected routes with higher weight limits.

In addition, detailed examination of actual railroad operating conditions, speed restrictions, tariffs, and accident rates could modify route selection and affect the resulting dose values.

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